Opportunistic Technique for Efficient Wireless Vehicular Communications

Javier Gozalvez and Miguel Sepulcre, University Miguel Hernández Elche, Spain

Abstract: *Vehicle-to-vehicle and vehicle-to-infrastructure wireless systems are currently under development to improve the traffic safety and efficiency while providing Internet connectivity on the move. A widespread adoption of these wireless vehicular communication technologies will require efficient use of the radio channel resources. To this end, this work proposes and analyzes an opportunistic-driven adaptive radio resource management (OPRAM) scheme that achieves the target traffic safety performance and efficiently uses the transmission and channel resources.*

The development of future vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications systems imposes strong radio channel management challenges due to their decentralized nature and the strict quality of service (QoS) requirements of traffic safety applications. To avoid road traffic collisions, vehicles will be required to periodically broadcast their position and speed to nearby vehicles using the IEEE 802.11p standard under development. The IEEE 802.11p system, usually referred to as wireless access in vehicular environments (WAVE) [1], adapts the IEEE 802.11a standard to the vehicular environment. It is based on seven 10-MHz channels consisting of one control channel and six service channels in the 5.9-GHz band. While the service channels are used for public safety and private services, the control channel is used as the reference channel to initiate and establish all communication links. As a consequence, the control channel is used to periodically broadcast announcements of available application services, warning messages, and safety status messages. Messages are transmitted in the control channel using the carrier sense multiple access with collision avoidance (CSMA/CA) access protocol, and the request to send/clear to send (RTS/CTS) signaling used

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TO AVOID ROAD TRAFFIC COLLISIONS, VEHICLES WILL BE REQUIRED TO PERIODICALLY BROADCAST THEIR POSITION AND SPEED TO NEARBY VEHICLES USING THE IEEE 802.11P STANDARD UNDER DEVELOPMENT.

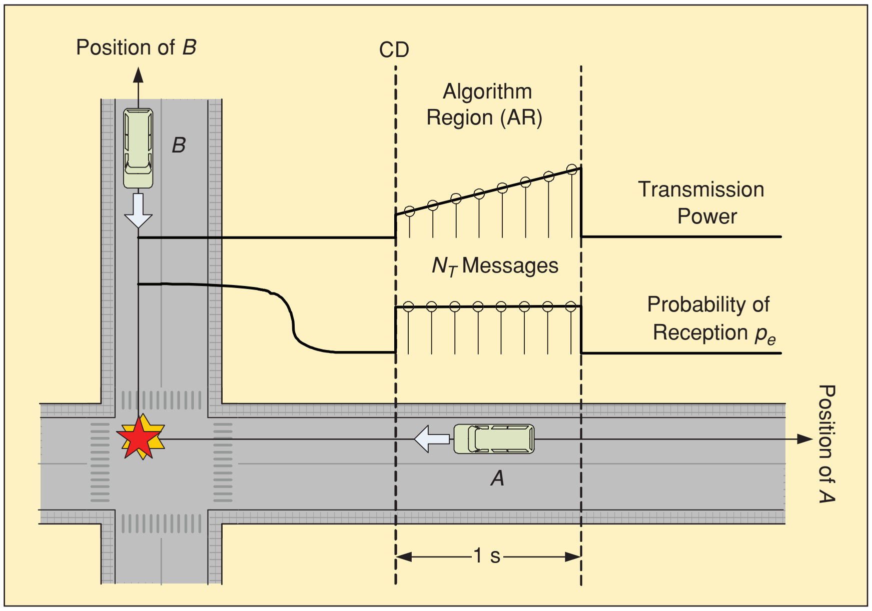

FIGURE 1 Intersection scenario and OPRAM proposal.

to avoid the hidden-terminal problem is disabled for broadcast messages. However, disabling the RTS/CTS transmissions, together with the reference use of the WAVE control channel in all V2V and V2I communications, requires the development of advanced radio resource management techniques that guarantee reliable and efficient use of the radio channel.

Previous studies have demonstrated the need to adapt the transmission parameters based on the operating conditions to efficiently use the radio resources [2]. In particular, the transmission power and packet data rates have been shown to heavily influence the wireless vehicular system performance. To date, the vehicular radio resource management research has generally focused on the system optimization of V2V data transmissions and system interference. For example, the work reported in [3] analyzes the combination of transmission power and packet data rate that optimizes the packet reception in highway scenarios. In [4], the authors propose a power control algorithm for vehicular ad hoc networks that dynamically changes the transmission power, based on the density of vehicles, to reduce channel collisions, given the number of vehicles within each vehicle's transmission range. Although these proposals improve the system's efficiency, it is important to consider the traffic safety performance requirements when developing advanced radio resource management schemes. In this context, this work proposes an opportunistic-driven adaptive radio resource management (OPRAM) scheme that adapts the transmission parameters (transmission power and packet data rate) based on the vehicle's position and its proximity to an area where a traffic collision could occur. By dynamically varying the communication settings, the proposed scheme not only guarantees the traffic safety application requirements but also efficiently uses the transmission resources and the radio channel.

TABLE 1 Simulation parameters

Parameter	Value
Speed [km/h]	70
Reaction time, RT [s]	0.75, 1.5
Emergency deceleration [m/s^2]	8
Packet size [B]	100
Background noise, N_o, [dBm]	−90

Evaluation Scenario

Before describing the proposed OPRAM algorithm, it is necessary to present the simulated traffic scenario. This work considers the urban intersection scenario depicted in Figure 1, where there is a potential risk of collision between vehicles *A* and *B*. To avoid such a collision, both vehicles periodically transmit broadcast safety messages on the WAVE control channel to detect each other's presence. Messages are transmitted at 6 Mb/s following the 1/2 quadrature phase shift keying (QPSK) transmission mode defined for the WAVE control channel. The studied scenario has been emulated through a wireless vehicular simulator developed in ns2. Table 1 summarizes the main simulation and configuration parameters established following the WAVE guidelines and [5].

A detailed urban microcell propagation model developed in the Wireless World Initiative New Radio (WINNER) project [6] has been considered to model the radio transmission effects defined in terms of path loss, shadowing, and multipath fading. Despite not considering V2V communication scenarios, the operating conditions of the WINNER urban microcell model are—to the knowledge of the authors—those that currently best fit the V2V communications scenario given the unavailability of a complete V2V communication propagation model for system-level investigations. In particular, the WINNER model considers a frequency range of 2–6 GHz and transmission and reception heights of 5 and 1.5 m, respectively. The model also differentiates between line-of-sight (LOS) and non–line-of-sight (NLOS) conditions, although in the scenario depicted in Figure 1 there will only be NLOS transmissions between vehicles A and B. For NLOS conditions, the WINNER path loss is expressed as follows:

$$PL_{\text{NLOS}} = PL_{\text{LOS}}(d_A[m]) + 20 - 12.5n_j + 10n_j \log_{10}(d_B[m]), \quad (1)$$

with

$$PL_{\text{LOS}} = \begin{cases} 22.7\log_{10}(d_A[m]) + 41 + 20\log_{10}(f\,[GH_z]/5), & \text{if } d_A < R_{bp} \\ 40\log_{10}(d_A[m]) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f\,[GH_z]/5) & \text{if } d_A \leq R_{bp,} \end{cases} \quad (2)$$

$$R_{bp} = 4\frac{(h_A - 1)(h_B - 1)}{\lambda}, \quad (3)$$

$$n_j = \max(2.8 - 0.0024\, d_A[m], 1.84), \quad (4)$$

with d_A and d_B representing the distances of vehicles A and B to the intersection and h_A and h_B their respective antenna heights.

The shadowing is modeled through a log normal distribution with a zero mean and a standard deviation equal to 4 dB for NLOS conditions. Finally, the fast fading effect resulting from the reception of multiple replicas of the transmitted signal at the receiver has also been implemented through a Rayleigh distribution.

To reduce the complexity of system-level simulations, the effects of the physical layer resulting from the probabilistic nature of the radio environment have been included by means of the look-up tables (LUTs) shown in Figure 2 [7]. These LUTs, extracted from link-level simulations, map the packet error rate (PER) to the experienced channel quality conditions expressed in terms of the effective signal to interference and noise ratio (SINR), E_{av}/N_0.

Opportunistic-Driven Adaptive Radio Resource Management Algorithm

Based on the scenario depicted in Figure 1, we define the critical distance (CD) as the minimum distance to the intersection at which vehicle A needs to receive a broadcast safety alert from vehicle B to avoid their potential collision at the intersection. Considering a uniform deceleration model, the critical distance can be computed as

$$\text{CD} = v \cdot RT + \frac{1}{2}\frac{v^2}{a_{\max}}, \quad (5)$$

where v represents the vehicle's speed, RT the driver's reaction time, and $a_{\max}$ the vehicle's emergency deceleration.

To efficiently use the WAVE control channel, it would be sufficient to correctly receive just one broadcast safety alert with the minimum signal level before reaching the CD. Through limiting the number of messages received and their signal level (and, hence, the transmitting power), it would be possible to increase the WAVE control channel's efficiency by reducing the channel congestion. In this context, this work proposes an OPRAM mechanism that adapts the transmission parameters (transmission power and packet data rate) based on the vehicle's position and its proximity to an area where a potential collision could occur.

THE TRANSMISSION POWER AND PACKET DATA RATES HAVE BEEN SHOWN TO HEAVILY INFLUENCE THE WIRELESS VEHICULAR SYSTEM PERFORMANCE.

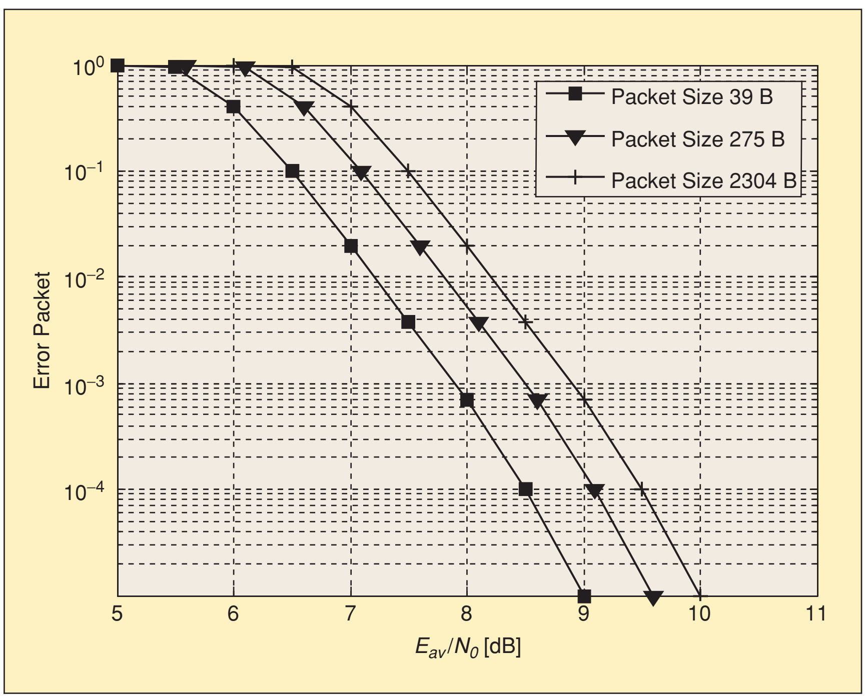

FIGURE 2 PER for the WAVE control channel.

TABLE 2 Probability of reception p_e for a varying N_T

N_T	p_e
10	0.37
20	0.2
40	0.11

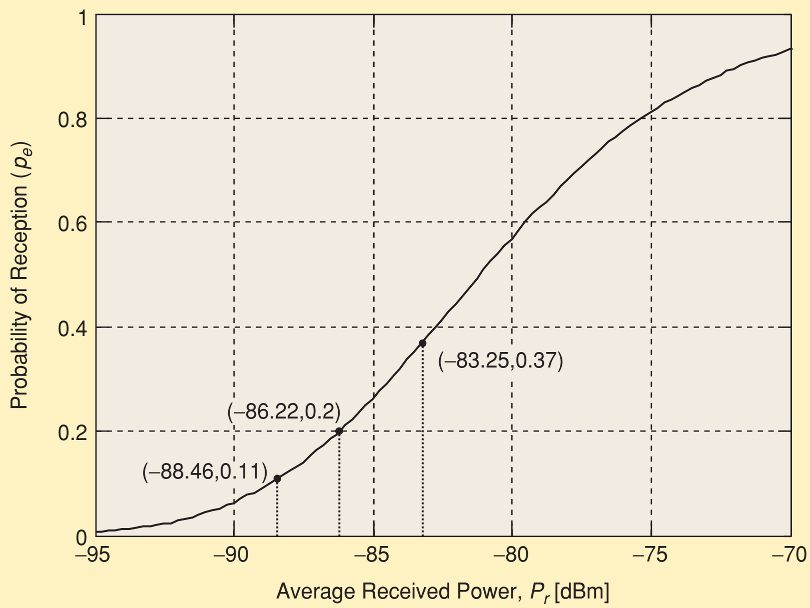

FIGURE 3 Average probability p_e as a function of P_r.

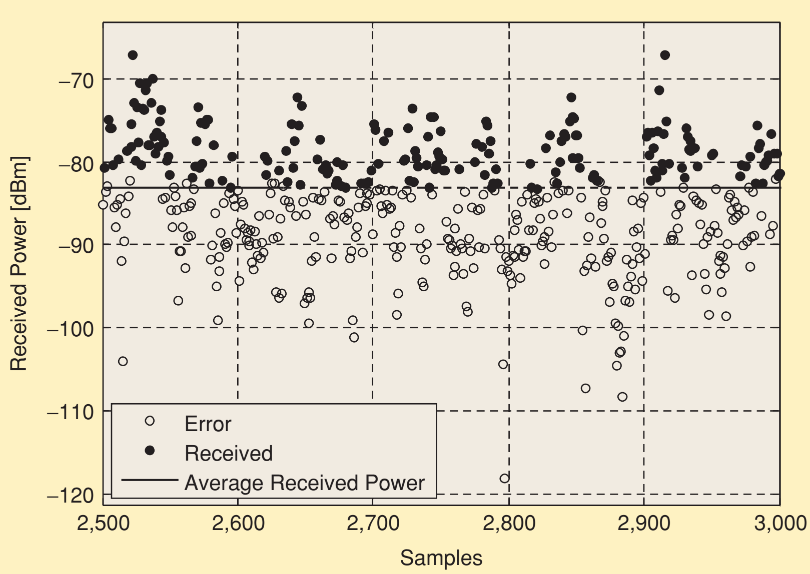

FIGURE 4 Instantaneously received samples for an average P_r equal to −83.25 dBm.

Considering the scenario reported in Figure 1, the OPRAM proposal operates with a low transmission power sufficient to communicate with the vehicles moving along the same street in LOS conditions, but increases its transmission power when the vehicle is approaching the CD. With such sudden increase, the aim of the OPRAM proposal is to guarantee the correct reception of a broadcast safety alert from vehicle B before reaching CD, while minimising the transmission power and, hence, maximising the channel's efficiency. The region before CD where OPRAM increases its transmission power is called the algorithm region (AR) and has been set to 1s for this work. To define the operation of the OPRAM proposal, we consider that each vehicle transmits N_T broadcast messages in the AR. The objective of the proposed algorithm has been set to successfully receive at least one broadcast message before reaching CD in 99% of the cases; this is equivalent to defining a probability of not receiving a warning alert before CD equals $p = 0.01$. Considering that OPRAM defines the probability that a single packet is successfully received p_e as independent and constant in the AR, the number of packets correctly received N_R in the AR can be described through a binomial distribution constructed by N_T Bernoully experiments (each of them with a probability of success p_e), i.e., $N_R \sim B(N_T, p_e)$. In this case, the probability that no broadcast message from B is received before CD is

$$P(N_R = 0) = (1 - p_e)^{N_T} = p. \quad (6)$$

Having defined p and N_T, p_e can be obtained through (6). Given that the aim is to maintain p_e constant in the AR, the OPRAM proposal requires a varying transmission power as shown in Figure 1. If N_T is increased, OPRAM can reduce the target mean probability p_e to successfully receive each transmitted packet within the AR (see Table 2). Once p_e has been calculated, Figure 3 is used to obtain the required average received power level P_r to successfully receive each transmitted packet within the AR with the probability p_e. Figure 3 has been obtained by separately evaluating a wide range of average received power levels, P_r. For each of these average P_r values, a large set of instantaneously received power level samples is generated by adding to the average P_r value the shadowing and fast fading contributions following their respective distributions. By computing E_{av}/N_0 and using Figure 2, it can be decided whether or not each sample is correctly received. The probability of successfully receiving a packet p_e given an average received power level P_r is then estimated as the ratio of correctly received samples to the total number of samples generated. Figure 4 illustrates the described process for $P_r = -83.25$ dBm, which corresponds to $p_e = 0.37$; black and white circles represent, respectively, correctly and erroneously received samples.

TO REDUCE THE COMPLEXITY OF SYSTEM-LEVEL SIMULATIONS, THE EFFECTS OF THE PHYSICAL LAYER RESULTING FROM THE PROBABILISTIC NATURE OF THE RADIO ENVIRONMENT HAVE BEEN INCLUDED BY MEANS OF THE LOOK-UP TABLES.

Once the mean P_r value necessary to guarantee the target p_e has been determined, the transmission power is obtained considering the distance between transmitter and receiver and the WINNER path loss expression. Figure 5 illustrates an example of the OPRAM operation. Following the observations extracted from Table 2, Figure 5 shows that an increasing value of N_T results in a lower p_e parameter and, hence, in significantly lower transmission power levels. As depicted in Figure 5, the OPRAM proposal maintains a constant 250-mW power level and a constant 10-packets/s data rate outside the AR. A 250-mW transmission power is sufficient to guarantee a vehicle's connectivity with those located along the same street in a 150-m range; this performance is required by the WAVE guidelines for cooperative collision warning applications [8]. By employing low transmission powers outside the AR, OPRAM also reduces the coverage range and channel collisions, which results in a more efficient use of the communications channel. While Figure 5 corresponds to a driver's RT of 1.5 s, Figure 6 illustrates the OPRAM operation for a driver's RT of 0.75 s. Lower RTs result in a shorter CD and lower OPRAM transmission powers (theoretically, even below 250 mW) given the reduced distances between vehicles A and B when entering the AR.

Performance

To analyse the benefits of the OPRAM proposal, this section first estimates, with regard to the traffic safety

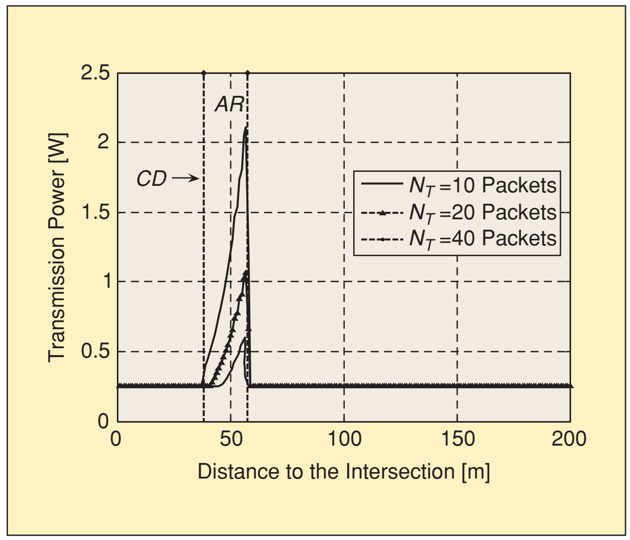

FIGURE 6 OPRAM operation for $RT = 0.75$ s.

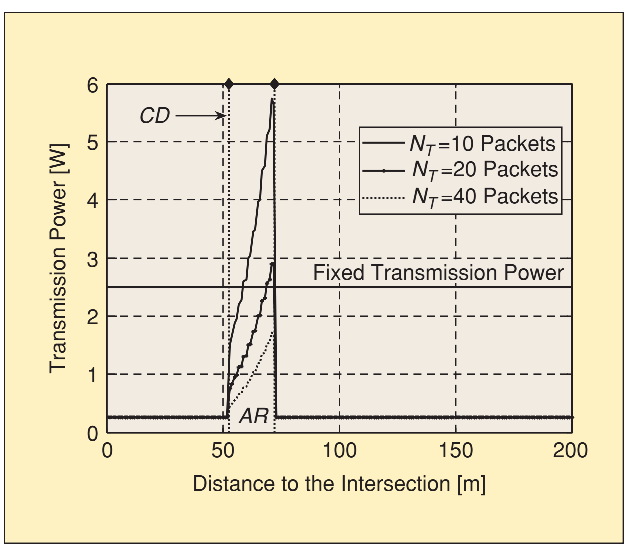

FIGURE 5 OPRAM operation for $RT = 1.5$ s.

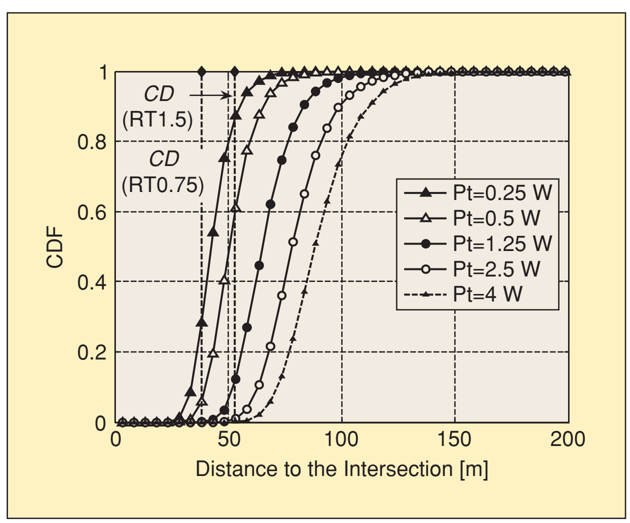

FIGURE 7 CDF of the distance at which the first message is received for constant transmission powers.

TO EFFICIENTLY USE THE WAVE CONTROL CHANNEL, IT WOULD BE SUFFICIENT TO CORRECTLY RECEIVE JUST ONE BROADCAST SAFETY ALERT WITH THE MINIMUM SIGNAL LEVEL BEFORE REACHING THE DISTANCE CD.

application under evaluation, the V2V communications performance using fixed transmitting powers. Figure 7 shows, for different transmission powers, the cumulative distribution function (CDF) of the distance to the intersection at which a vehicle correctly receives the first broadcast safety message from the potentially colliding vehicle. The figure also shows the critical distance for the two considered driver's RTs. The probability of accident, i.e., the probability of not receiving an alert before CD, can then be defined as the intersection of the CDF curve with CD. The results depicted in Figure 7 show that the transmission power necessary to avoid an accident varies with the driver's reaction time. In particular, for large driver's *RTs*, the V2V communications system would have to employ large transmission powers to avoid a collision at the intersection. Figure 8 represents the probability of correctly receiving a broadcast message as a function of the distance to the intersection. As shown in Figure 8, the probability of correctly receiving a message rapidly decreases with the distance, even when using high transmission powers. This observation questions the need to constantly transmit at high power levels for the traffic safety application under study given that high transmission powers result in increased transmission ranges and higher channel collisions due to the hidden-terminal problem. The results illustrated in Figure 8 also show that the higher probability of correctly receiving a broadcast safety alert is obtained after CD, i.e., when the alert is of limited use to prevent the collision at the intersection. The observations extracted from Figure 8 highlight the inefficient use of the WAVE control channel with fixed transmitting power levels and the need to develop adaptive proposals, such as OPRAM, that modify the transmission parameters based on the safety applications requirement and the aim to maximise the channel's efficiency.

Figure 9 shows the percentage of vehicles that receive a given number of messages before CD considering the OPRAM proposal and a fixed transmitting power of 2.5 W. As shown in Figure 9, a 2.5-W transmission power was needed to correctly receive a broadcast safety alert in 99% of the cases for a 1.5-s driver's *RT*. The results shown in Figure 9 demonstrate that the OPRAM proposal is able to provide the same traffic safety performance as using a constant high transmission power while significantly reducing the global

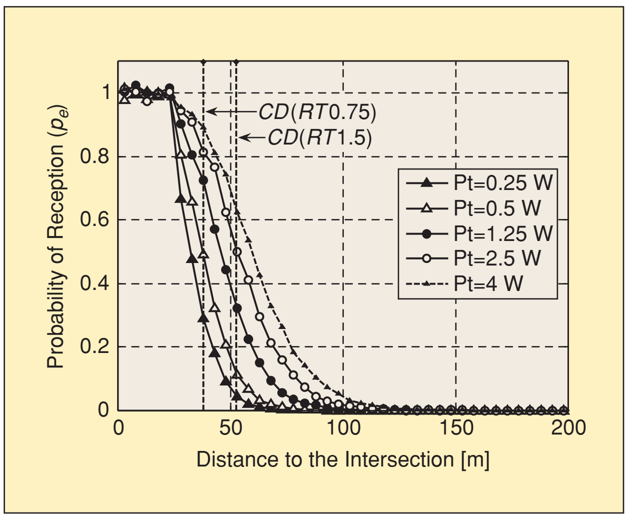

FIGURE 8 Probability of successful reception versus distance to the intersection.

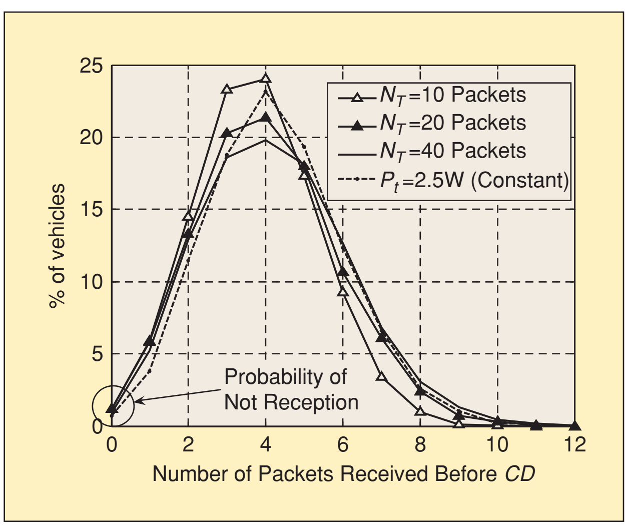

FIGURE 9 Percentage of vehicles that receive a given number of messages before CD for a driver's $RT = 1.5$ s.

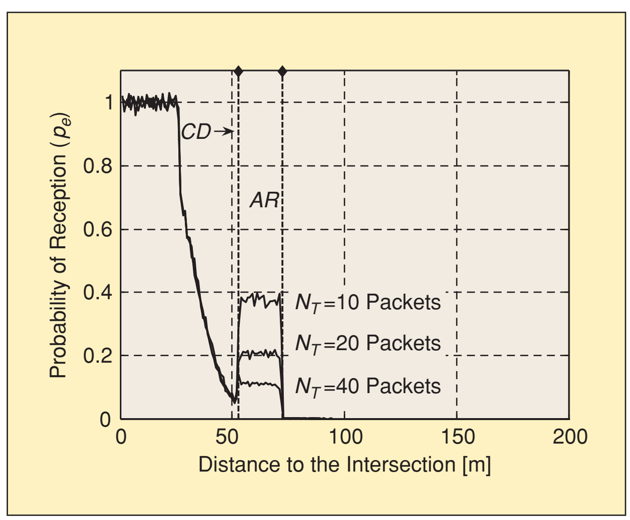

FIGURE 10 Probability of successful packet reception from the potentially colliding vehicle for $RT = 1.5$ s.

transmitting power levels, as shown in Figure 7. (As previously mentioned, low transmission powers reduce the coverage range and, therefore, the channel congestion derived from the hidden-terminal problem.) The reduction in transmission power is even more significant as the value of N_T within the AR is increased (Figure 7), while still guaranteeing the target traffic safety performance. The OPRAM proposal offers then an interesting option to tradeoff transmission power and packet data rate while maintaining the traffic safety performance and efficiently using the WAVE control channel. Figure 10 represents the probability of successful reception of a broadcast safety alert considering the OPRAM proposal. First of all, Figure 10 shows that OPRAM achieves a constant p_e during the AR that decreases with higher values of N_T. Also, it is important to note that OPRAM achieves the same traffic safety performance as constantly transmitting at high power levels despite experiencing a p_e equal to zero outside the AR. (This probability corresponds to the probability of successfully receiving a broadcast safety alert between vehicles A and B, and not between vehicles moving along the same street for which p_e will not be equal to zero.) These observations highlight that OPRAM results in a more efficient use of the transmission and channel resources since it reduces the power consumption and radiation and the channel congestion probability.

THESE OBSERVATIONS HIGHLIGHT THAT OPRAM RESULTS IN A MORE EFFICIENT USE OF THE TRANSMISSION AND CHANNEL RESOURCES.

Conclusions

The strict traffic safety latency requirements and the decentralized nature of V2V communications systems impose strong radio resource management challenges to guarantee the viability of wireless vehicular communications systems. In this context, this work has proposed an OPRAM technique that guarantees the traffic safety performance while efficiently using the transmission and radio resources.

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Author Information

Javier Gozalvez received an electronics engineering degree from the French Engineering School ENSEIRB, a DEA in electronics from Université de Bordeaux I, France, and a Ph.D. in mobile communications from the University of Strathclyde, Glasgow, U.K. Since October 2002, he has been with the Signal Theory and Communications Division of the University Miguel Hernández, Elche, Spain, where he is currently an associate professor and Director of the Uwicore Research Laboratory. At Uwicore, he is leading research activities in the areas of wireless vehicular communications, radio resource management, heterogeneous wireless systems, and wireless system design and optimization. He currently serves as Associate Editor of *IEEE Communication Letters* and as Mobile Radio Senior Editor of *IEEE Vehicular Technology Magazine*, where he leads a team of six Associate Editors. He also serves on the editorial board of *Journal of Communications* and *Journal of Networks* (both of Academic Publishers), as chair of the Ad-hoc Vehicular Communications Technical Committee of the IEEE Vehicular Technology Society, and as member of the Telecommunications Technical Committee of the International Association of Science and Technology for Development (IASTED). He is general cochair and founder of the IEEE International Symposium on Wireless Vehicular Communications (WiVeC) and the 3rd International Symposium on Wireless Communications Systems (ISWCS). He is speakers chair for the IEEE Vehicular Technology Conference Spring (2004, 2005, 2007), and technical program committee member for various international conferences.

Miguel Sepulcre received a telecommunications engineering degree in 2004 and a DEA in communications technologies in 2007, both from the University Miguel Hernández, Elche, Spain. In 2004, he spent six months at the European Space Agency (ESA) in Noordwijk, The Netherlands, working on the communications physical layer of earth exploration satellites. In 2005, he joined the University Miguel Hernández as a networks manager and teaching assistant. In March 2006, he obtained a Ph.D. fellowship from the Valencian regional government and joined the Uwicore research laboratory. He is currently pursuing his Ph.D. at Uwicore, working on wireless vehicular communications and, in particular, in the development of adaptive and efficient radio resource management techniques for V2V wireless communications systems. His current research interests include wireless vehicular communications, radio resource management, and modeling and simulation of wireless communications systems.

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